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RATE OF SPREAD OF FIRE AND ITS RESISTANCE TO CONTROL IN THE FUEL TYPES OF EASTERN MOUNTAIN FORESTS

A Progress Report

By

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Successful forest fire control depends to a large extent on the efficient distribution of permanent fire control facilities -- detection stations, roads, trails, and fire guard stations -- with respect to normal fire occurrence, fuel types, and values at stake. These three factors also have a bearing on the degree of preparedness to be adopted by a fire control organization from day to day as fire weather conditions change. After a fire starts, the dispatch of suppression forces is influenced by fuel type and values involved.

A study has been under way at the Appalachian Forest Experiment Station to determine for fire planners reliable averages of the rate of spread and resistance to control of fires burning in major fuel types. Eventually it is hoped that sufficient data will be available to supply fire dispatchers with a manpower meter to guide their suppression action.

In 1937, C. A. Abell prepared a preliminary statement[1/] on the rate of spread and resistance to control of fires burning in 14 fuel types recognized in the eastern region[2/] of the United States. The importance of fuel type as a factor influencing speed and strength of attack requirements was established from records of 1,560 fires which occurred during 1930 to 1936.

The analysis to be discussed here adds data for the four-year period 1937 to 1941 to those used by Abell, and includes a more specific appraisal of

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[1/] Abell, C. A. Rate of spread and resistance to control data for Region 7 fuel types and their application to determine strength and speed of attack needed. Appalachian Forest Experiment Station, Asheville, N. C. 7 p. ill. Mimeographed. October 5, 1937

[2/] This region includes the southern Appalachians northward from Virginia, Alleghenies, White and Green Mountains, adjacent plateaus and mountain valleys.

variations in rate of spread and resistance to control associated with different burning conditions than was possible at the time of the earlier report. Approximately 3,200 fires for the period 1930 to 1941 on the seven eastern national forests are included. This study is not a complete analysis of fire reports but is specifically limited to the phases mentioned.

As in the first investigation, certain limitations and inadequacies of fire report records must be mentioned. Time of origin and perimeter on arrival are, of course, estimates, but every precaution was taken to eliminate reports that were unquestionably in error. For example, any fires which had an impossibly small perimeter or an improbably large perimeter for their acreage were eliminated. Fires distant from a station where fire danger was being measured or those which burned in areas not represented by a danger station were excluded from the compilations involving fire intensity. Finally, all fires having an origin-to-arrival time in excess of 8 hours, about 5 percent of the total number, were eliminated.

FIRE OCCURRENCE BY FUEL TYPES

As indicated in table 1, most fires have occurred in the northern or Appalachian hardwood fuel types, either in stands where trees average 3 to 4 inches or larger, or in areas supporting reproduction, and in grass-weed fuels. Seventy-nine percent of all fires for the period 1930 to 1941 were in these fuels types, numbers 4, 5, and 11. This is undoubtedly a close representation of the area occupied by these fuel types. Southern pine 6 inches or larger (type 6) rates fourth with respect to number of fires, and hardwood or southern pine slash fuels (type 10) rate fifth. These five fuel types, 4, 5, 6, 10, and 11, account for 91 percent of all fires.

RATE OF SPREAD

The rate at which free-burning fires increase their perimeter under different combinations of fuel type and burning conditions is one of the most important things a dispatcher must know and consider in determining how many men to send to each fire in his district. The present study does not provide sufficient information to serve the dispatcher directly in this way, but it does give averages that may be used as guides in dispatching or that should be helpful in setting up speed and strength of attack standards. Appreciation of rate of spread in different fuel types is particularly essential at this time when fire control is being extended to war-industry areas and when much dispatching is the responsibility of new, inexperienced men.

In most Forest Service regions it has been customary to classify fuel types, with respect to rate of spread, into the four classes low, medium, high and

extreme. The 14 fuel types used in the eastern region were chosen because of the ease and accuracy with which they could be classified by many individuals. It is now possible to assign definite rate of spread figures to these 14 fuel types and to group them into the four standard classes for comparison with other regions.

To make such a classification for the eastern region, average rates of spread for all fires by fuel types were compared and found to differ by statistically significant amounts with but two minor exceptions. They were therefore grouped arbitrarily into the customary four classes low, medium, high and extreme, by dividing the range in average rate of spread into four equal parts. In this procedure fuel types 2 and 10 were found to be borderline cases, and since these types were not statistically different compared to others with a greater weighting, type 2 was classed as high and type 10 as medium. Average rates of spread are given in table 2 with the general group classification.

It will be noted in table 2 that average rates of spread vary from 12.1 chains perimeter increase per hour to 35.6 chains. Classes representing the four standard groups are as follows with the weighted average rates of spread:

Group	Range	Weighted average
Low	18 chains or less	14.0 chains
Medium	19 to 24 chains	21.8 "
High	25 to 30 "	26.9 "
Extreme	31 chains or more	34.7 "

In this classification 1.1 percent of all eastern region fires occur in low rate of spread fuels, 76.9 percent in medium, 21.2 percent in high, and 0.8 percent in extreme.

An appreciation of the variability in rate of spread within each of the given fuel types can be gained from the last column of table 2 where average rates of spread for the 25 percent of the fastest spreading fires are given. These high rates of spread are most likely to be associated with the fires that "get away" and cause most of the losses in the eastern region. The fire plan must recognize and allow for the fact that one out of every four fires spreads at least as fast as the rates shown, and appropriate speeds and strengths of attack should be provided to handle such fires. Further, the variability of spread within a fuel type is shown by the percentages of fires spreading at various rates (table 3). For example, the table indicates that in type 4, 15 percent of all fires spread 15 to 20 chains per hour, 3 percent spread 45 to 50 chains per hour.

The importance of rapid-spreading fires is emphasized when the data are tabulated as in table 4 which shows the proportion of fires spreading as fast or faster than 30, 50, and 70 chains per hour.

Part of the variability of rate of spread in a given fuel type can be explained by differences in burning conditions during each fire. Measurements of fire danger applicable to some of the fires permit a classification of rate of spread by fire danger classes for the major fuel types. Figure 1 shows this relation for fuel types 4, 5, and 11, as well as a composite curve for all fuel types. As would be expected, there is a material increase in rate of spread as fire danger increases. Types 4 and 5, both primarily leaf litter fuels, have rates of spread identical to class 1, 2, and 3 conditions but differ slightly at higher danger, type 5 giving the fastest spread. For some unexplained reason, fires in grass fuels (type 11) change rate of spread less as danger increases (in the higher ranges) than do the fires in other fuel types.

There is still considerable variation in rate of spread within any one fuel type and danger class. This is due to slope, aspect in relation to wind direction, and many other factors not measured in either fuel type or fire danger classification. Such variation prevents the use of the data in this report as a reliable basis for dispatching men to fires.

RESISTANCE TO CONTROL

An appreciation of the difficulty of constructing held fire line is as important as a knowledge of rate of spread in different fuel types. Fire planners must know the resistance to control offered by each fuel type if they are to arrive at an intelligent appraisal of manpower needs to meet a given objective.

Average rates of held line construction per man-hour to control have been computed for each fuel type and are tabulated for 1930 to 1941 in table 5. These rates vary from 0.4 to 3.2 chains per man-hour and this range has been divided into four equal parts called low, medium, high, and extreme resistance to control in keeping with standard practice in other regions. The classification is shown by symbol in table 5. The classes representing the four resistance to control groups are as follows; weighted averages for each group are given:

Group	Range	Weighted average
Low	2.5 or more chains per man-hour	3.1 chains per man-hour
Medium	1.8 to 2.4 " " "	2.1 " " "
High	1.1 to 1.7 " " "	1.5 " " "
Extreme	1.0 or less " " "	0.6 " " "

Of the total number of fires, 29.7 percent are in fuels rated as low resistance to control, 65.9 percent in medium, 3.3 percent in high, and 1.1 percent in the extreme group.

There is little definite trend between output of held line and fire danger class for the different fuel types, but when all fuel types are grouped, the relation appears as in figure 2. In explanation of the shape of this curve, it can be conjectured that output is low on "easy" days (class 1 and 2) because such fires are generally over-manned. It is easy to send too many men to a slow-burning fire. On "bad" days (class 4 and 5) it is almost impossible to over-man fires, but because of spotting, heat of fire, lost line, and other factors, output is even lower than on class 1 and 2 days. Apparently greatest efficiency in manning fires is accomplished on class 3 days when the peak of production is reached.

FINAL AREA OF THE AVERAGE FIRE

Since some dispatchers and fire planners are accustomed to thinking in terms of area, table 6 has been added to show the differences in average size of fire by fuel types. There is, of course, a marked relation between average final area and fire danger class, shown in figure 3.

SUMMARY

A re-analysis of C. A. Abell's fire report data, previously published, with the addition of 1937 to 1941 figures was made to determine the importance of the 14 eastern region fuel types in influencing the rate of spread of fire and its resistance to control. Table 7 summarizes the findings brought out in the text of the report, and shows that 77 percent of all fires occur in the "medium" rate of spread fuels and 66 percent in the "medium" resistance to control group. The relation of rate of spread, held line output, and area burned to fire danger class is given.

Averages presented in this report should not be used directly by the fire dispatcher but should serve as a general guide to his judgment. They should also be of value in fire planning when it is necessary to establish speed and strength of attack standards.

Table 1.-Number of fires by fuel types.
1930 to 1941 data

No.	Fuel type — Description	Number of fires	Percent of total
1	Northern conifers 4" and up......................	14	0.5
2	Northern conifer, cutover, duff, non-slash......	24	0.9
3	Hardwood and hemlock-hardwood, cutover, slash and duff absent................................	55	2.1
4	Northern and Appalachian hardwoods 3-4" and up..	914	35.1
5	Hardwood reproduction............................	634	24.4
6	Southern pine 6" and up..........................	161	6.2
7	Southern pine reproduction.......................	97	3.7
8	Conifer slash - new..............................	15	0.6
9	Conifer slash - old..............................	12	0.5
10	Hardwood and southern pine slash................	141	5.4
11	Grass, ferns, and weeds.........................	516	19.8
12	Plantations.....................................	No data	
13	Laurel and rhododendron.........................	7	0.3
14	Scrub oak.......................................	13	0.5
Total		2,603	100.0

Table 2.--Average rate of spread and rate of spread of fastest spreading 25 percent of all fires, with origin-to-arrival time of 8 hours or less. 1930 to 1941 data

No.	Fuel type: Description	Average rate of spread, all fires	Group classification 1/	Rate of spread of fastest spreading 25 percent
		Chains perimeter per hour		Chains perimeter per hour
1	Northern conifers 4" and up.......	12.1	L	21.7
2	Northern conifer, cutover, duff, non-slash......................	30.2	H	86.7
3	Hardwood and hemlock-hardwood, cutover, slash and duff absent..	22.3	M	55.7
4	Northern and Appalachian hardwoods 3-4" and up..................	20.7	M	47.4
5	Hardwood reproduction.............	21.5	M	51.3
6	Southern pine 6" and up...........	22.7	M	53.0
7	Southern pine reproduction........	25.1	M	55.2
8	Conifer slash - new...............	15.8	L	35.8
9	Conifer slash - old...............	26.2	H	67.5
10	Hardwood and southern pine slash..	25.4	M	60.9
11	Grass, ferns, and weeds...........	26.8	H	58.8
12	Plantations.......................	- - -	No data	- - -
13	Laurel and rhododendron...........	33.1	E	83.2
14	Scrub oak.........................	35.6	E	85.2
Average all fuel types		22.9		52.7

1/L low rate of spread.
M medium rate of spread.
H high rate of spread.
E extreme rate of spread.

Table 3.-Percent of fires spreading at various rates by fuel types.
1930 to 1941 data

Rate of spread	Fuel type													All types
	1	2	3	4	5	6	7	8	9	10	11	13	14	
Chains per hour	- Percent -													
0-5.0	21	25	15	13	11	7	5	27	25	16	8		15	11.0
5.1-10.0	22	17	25	20	20	23	19	20	17	17	15	14	23	19.0
10.1-15.0	28	16	11	17	21	18	13	13	8	11	14	57	8	17.0
15.1-20.0	22		18	15	16	17	15	7		10	15	15		15.0
20.1-25.0		9	4	9	8	9	9		8	10	6		8	8.0
25.1-30.0	7	4	2	6	6	7	10	6	17	7	9			7.0
30.1-35.0		4	3	5	4	3	8	7		8	9		8	5.0
35.1-40.0		8	6	4	2	1	3	13		5	5			4.0
40.1-45.0		9	3	1	2	2	6	7		2	5			3.0
45.1-50.0		4	2	3	2	2	4			3	3		15	2.3
50.1-55.0				1	1				8	1	1			0.9
55.1-60.0				1	0.7	2	3			2	2			1.4
60.1-65.0				1	0.3	1	2		9	1.6	1			0.8
65.1-70.0			6	0.7	1.1	3					1		8	1.1
70.1-75.0			3	0.3	0.6	0.7					1			0.5
75.1-80.0				0.3	1.1	0.6					1			0.6
80.1-85.0				0.5	0.2		1			0.7	1.1			0.5
85.1-90.0				0.1	0.3	0.6			8	1.4				0.2
90.1-95.0				0.3	0.2	0.6							7	0.3
95.1-100.0				0.6	0.4	1.3	1			1.5	0.4			0.6
100.1-105.0						0.6					0.2			0.1
105.1-110.0				0.2	0.2					0.7	0.4			0.2
110.1-115.0				0.2	0.6						0.3		8	0.4
115.1-120.0				0.4	0.2					0.7	0.6			0.3
120.1-125.0			2	0.1	0.2									0.1
125.1-130.0					0.1	0.6					0.2			0.2
130.1-135.0					0.2					0.7	0.2			0.2
135.1-140.0											0.2			
140.1-145.0											0.2			
145.1-150.0				0.1	0.1									0.1
150.1-155.0				0.1			1					14		0.2
155.1-160.0				0.1										
160+		4			0.5					0.7	0.2			0.2

Table 4.--Percent of fires spreading 30, 50 and 70 chains or more perimeter per hour by fuel types. 1930 to 1941 data

No.	Fuel type	Percent of fires spreading-		
	Description	30 chains or more per hour	50 chains or more per hour	70 chains or more per hour
1	Northern conifers 4" and up...........	0	0	0
2	Northern conifer, cutover, duff, non-slash..........................	29	4	4
3	Hardwood and hemlock-hardwood, cutover, slash and duff absent...............	25	11	5
4	Northern and Appalachian hardwoods, 3-4" and up.........................	20	7	3
5	Hardwood reproduction.................	18	8	5
6	Southern pine 6" and up...............	19	11	5
7	Southern pine reproduction............	29	8	3
8	Conifer slash - new...................	27	0	0
9	Conifer slash - old...................	25	25	8
10	Hardwood and southern pine slash......	29	11	6
11	Grass, ferns, and weeds...............	33	11	6
12	Plantations...........................	--	No data	--
13	Laurel and rhododendron...............	14	14	14
14	Scrub oak.............................	46	23	15

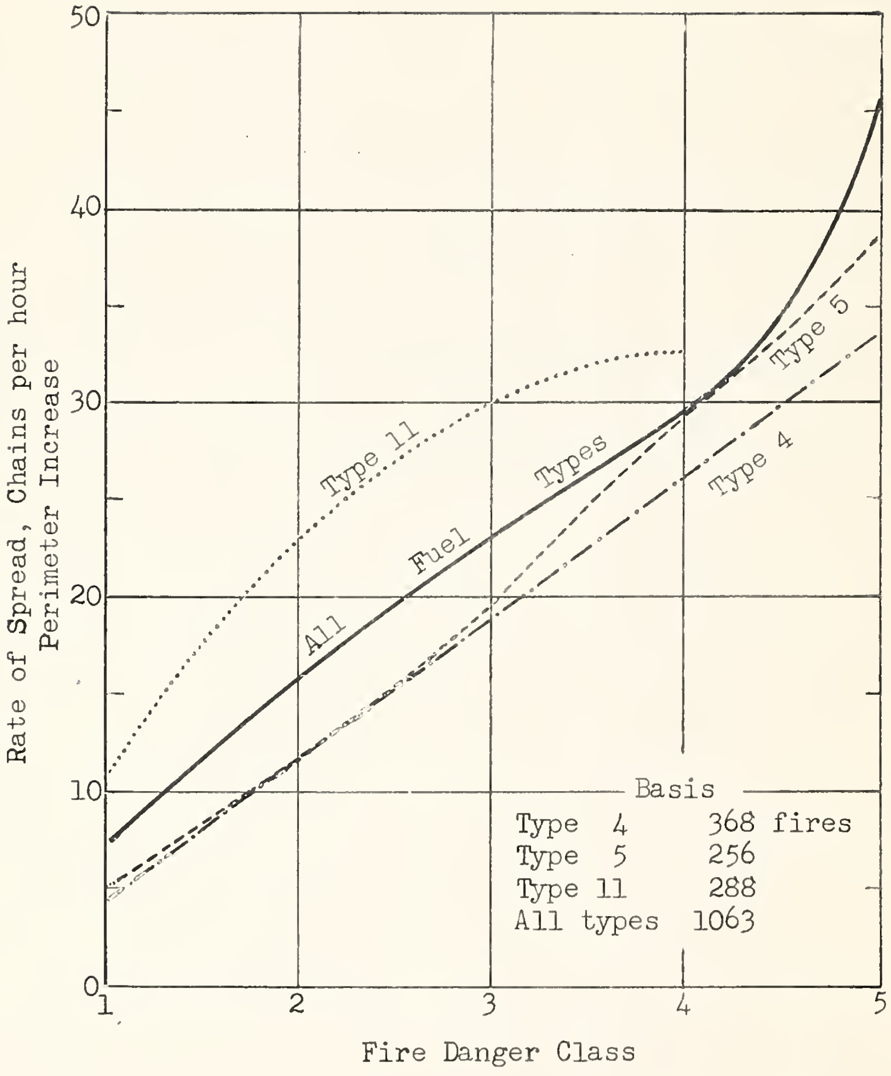

Fig. 1 - Relation of rate of spread to fire danger class for fuel types 4, 5, 11 and composite of all types.

Table 5.-Average rate of held line construction by fuel types, in chains per man-hour to control.
1930 to 1941 data

No.	Fuel type: Description	Number of fires	Avg. rate of held line construction, chains per man-hour to control	Resistance to control classification 1/
1	Northern conifers 4" and up.............	22	1.8	M
2	Northern conifer, cutover, duff, non-slash...........................	35	1.3	H
3	Hardwood and hemlock-hardwood, cutover slash and duff absent................	69	1.6	H
4	Northern and Appalachian hardwoods, 3-4" and up.........................	1,114	2.1	M
5	Hardwood reproduction.................	788	2.1	M
6	Southern pine 6" and up................	206	2.8	L
7	Southern pine reproduction.............	120	2.9	L
8	Conifer slash -- new....................	17	0.4	E
9	Conifer slash - old.....................	13	0.7	E
10	Hardwood and southern pine slash........	176	1.8	M
11	Grass, ferns and weeds.................	654	3.2	L
12	Plantations............................	-- --	[illegible]	
13	Laurel and rhododendron.................	11	1.3	H
14	Scrub oak...............................	16	1.9	M
	Total or average, all types	3,241	2.3	

1/L low resistance to control.
M medium resistance to control.
H high rate of spread.
E extreme rate of spread.

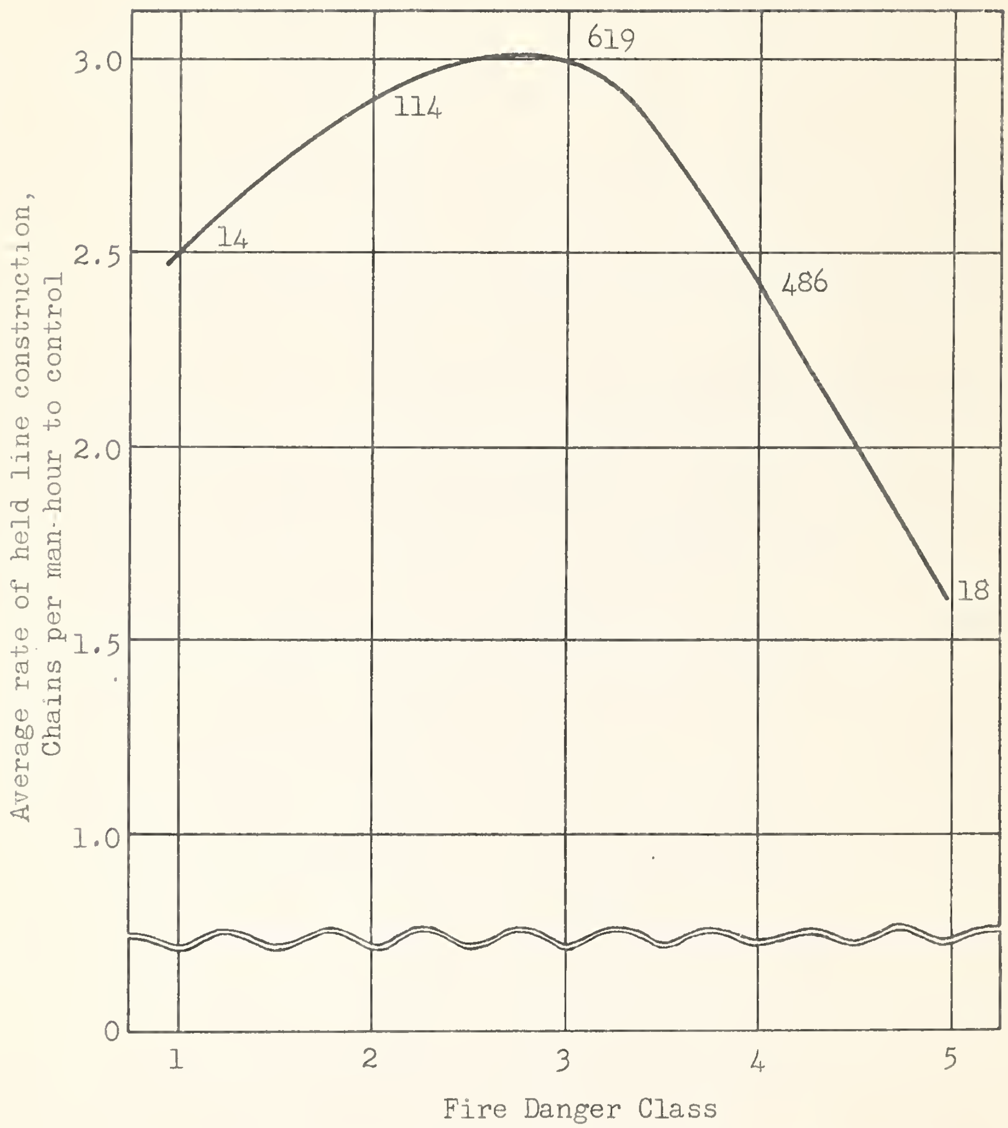

Fig. 2 - Average rate of held line construction by fire danger classes, all fuel types combined, 1937 to 1941 data

Table 6.--Average final area by fuel types.
1930 to 1941 data

No.	Fuel type: Description	Number of fires	Average final area (Acres)
1	Northern conifers 4" and up	22	12
2	Northern conifer, cutover, duff, non-slash	35	76
3	Hardwood and hemlock-hardwood, cutover slash and duff absent	69	22
4	Northern and Appalachian hardwoods, 3-4" and up	1,134	24
5	Hardwood reproduction	792	23
6	Southern pine 6" and up	206	16
7	Southern pine reproduction	120	11
8	Conifer slash - new	18	83
9	Conifer slash - old	14	22
10	Hardwood and southern pine slash	176	36
11	Grass, ferns and weeds	666	18
12	Plantations	No data	
13	Laurel and rhododendron	11	48
14	Scrub oak	16	48
	Total or average, all types	3,279	23

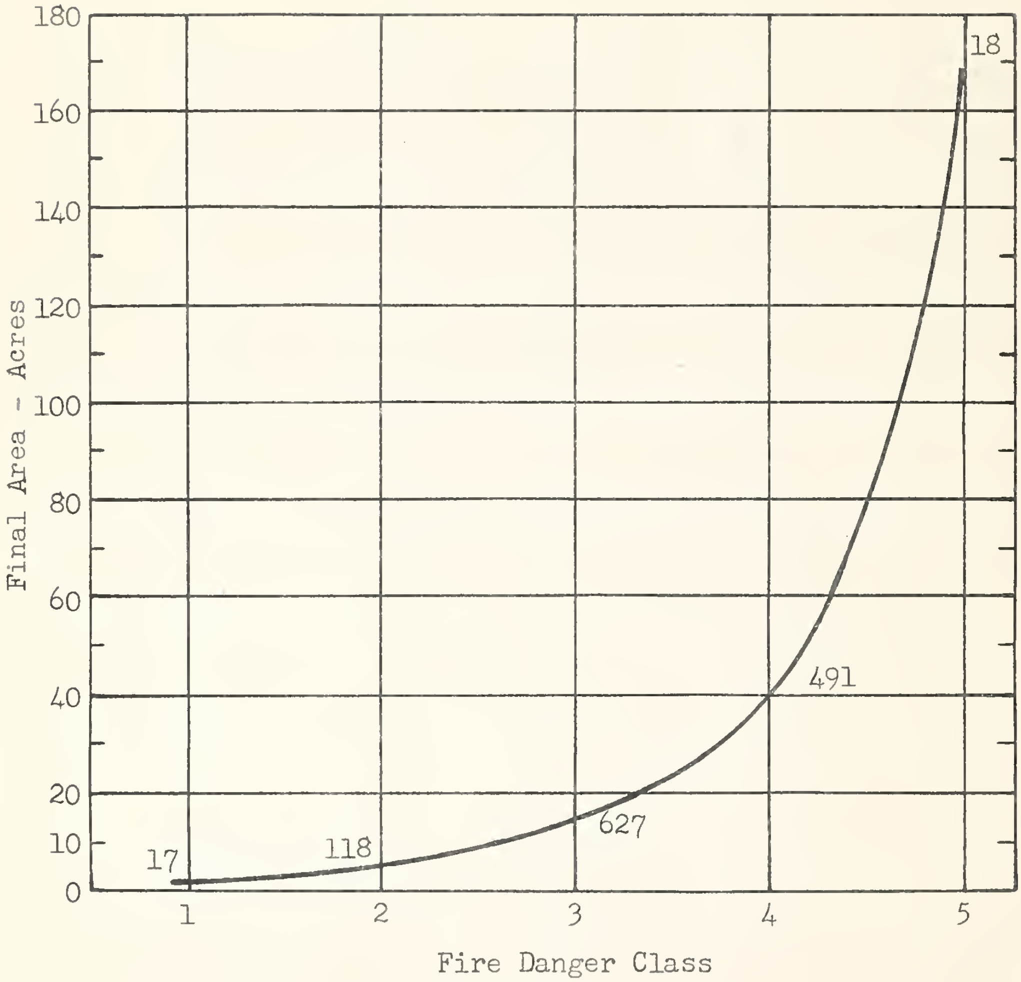

Fig. 3 -- Final area by fire danger classes. All fuel types combined. 1937 to 1941 data.

Table 7.--Summary of rate of spread and resistance to control by fuel types. 1930 to 1941 data

(Fuel type number and percent of total fires)

Resistance to control	Rate of spread				All fires	Average rate of line construction, chains per man-hour
	Low	Medium	High	Extreme		
Low		Fuel type #6, 7 9.9%	Fuel type #11 19.8%		29.7%	3.1
Medium	Fuel type #1 0.5%	Fuel type #4, 5, 10 64.9%		Fuel type #14 0.5%	65.9%	2.1
High		Fuel type #3 2.1%	Fuel type #2 0.9%	Fuel type #13 0.3%	3.3%	1.5
Extreme	Fuel type #8 0.6%		Fuel type #9 0.5%		1.1%	0.6
All fires	1.1%	76.9%	21.2%	0.8%	100.0%	2.3
Average rate of spread--chains perimeter per hour	14.0	21.8	26.9	34.7	22.9	